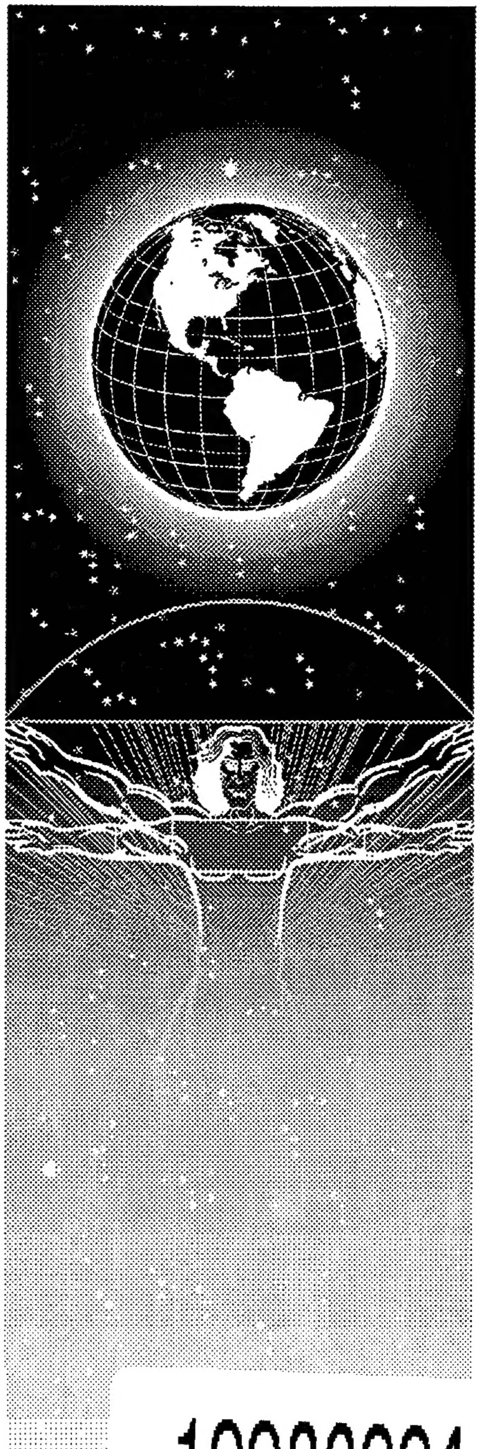
AL/HR-TP-1997-0054



UNITED STATES AIR FORCE
ARMSTRONG LABORATORY

Evaluation Method for Simulated Human Motion

Jeff L. Wampler
Robert Hale
Scott Ziolek
Tom Bridgman

HUMAN RESOURCES DIRECTORATE
Logistics Research Division
2698 G Street
Wright-Patterson Air Force Base, Ohio 45433 7604

October 1997

Approved for public release; distribution is unlimited

Human Resources Directorate
Logistics Research Division
2698 G Street
Wright-Patterson AFB OH
45433-7604

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation, or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Public Affairs Office has reviewed this paper and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This paper has been reviewed and is approved for publication.

JEFF L. WAMPLER
Program Manager

LOUIS M. JOHNSON, LTC, USAF
Chief, Logistics Research Operations

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 1997

3. REPORT TYPE AND DATES COVERED
Interim - Jun 1996 to Jan 1997

4. TITLE AND SUBTITLE
Evaluation Method for Simulated Human Motion

5. FUNDING NUMBERS
C - N/A
PE - 62106F
PR - 2940
TA - 00
WU - 10

6. AUTHOR(S)
Jeff L. Wampler, Robert Hale, Scott Ziolek and Tom Bridgman

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Armstrong Laboratory
Human Resources Directorate
Logistics Research Division
2698 G. Street
Wright Patterson AFB, OH 45433-7604

8. PERFORMING ORGANIZATION REPORT NUMBER
AL/HR-TP-1997-0054

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory
Human Resources Directorate
Logistics Research Division
2698 G. Street
Wright Patterson AFB, OH 45433-7604

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
AL/HRG Technical Monitor: Jeff L. Wampler, AL/HRGA, (937)-255-7773

12a. DISTRIBUTION AVAILABILITY STATEMENT

Approved for public release: distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Computer generated human figures, called human figure models (HFMs), are being used for human factors design and maintenance analysis on solid models of Department of Defense system designs. The reliability of products from HFM design analyses are dependent on the accuracy of the human model. This paper describes a method for evaluating the accuracy of an HFM compared to real human motion. Although the evaluation is being performed on the HFM in the Design Evaluation for Personnel, Training and Human Factors (DEPTH) system, the method can be applied to any commercially-available HFM.

14. SUBJECT TERMS
Human Figure Models (HFM) Computer Aided Design (CAD) Human Factors
Design Evaluation for Personnel, Training and Human Factors (DEPTH)
Maintenance TransomJack

15. NUMBER OF PAGES
20

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

Standard Form 298 (Rev. 2-89) (EG)
Prescribed by ANSI Std. 239.18
Designed using Perform Pro, WHS/DIOR, Oct 94

CONTENTS

FIGURES

TABLES

Preceding Page Blank

PREFACE

Recent advances in computer graphics have allowed designers to place simulated humans in solid models of systems for design analyses. These simulated humans, called human figure models (HFMs), are being used for visual and quantitative workspace design and maintenance analysis. There are several commercially available HFMs, each with its own unique characteristics. All of these models have one thing in common: the products of design analyses are dependent on the accuracy of the human model. This paper describes a method for evaluating the accuracy of an HFM compared to real human motion. A study is being conducted which uses this methodology on the Design Evaluation for Personnel, Training and Human Factors (DEPTH) software at AL/HRGA, Wright-Patterson Air Force Base. The results of this work will be published in a future technical paper. Although the evaluation is being performed on the HFM in the DEPTH system, the method can be applied to any commercially-available HFM.

The principal investigator for this research is Robert Hale, Battelle Memorial Institute, Contract Number F33657-92-D-2055, Task Number 123. This research is being conducted under AL/HRGA Work Unit 29400010, Acquisition Logistics Visualization Laboratory.

INTRODUCTION

Armstrong Laboratory, Logistics Research Division (AL/HRGA) is developing demonstration software called the Design Evaluation for Personnel, Training, and Human Factors (DEPTH) for use in weapon system design (Boyle et al., 1990). The software is being used to evaluate the maintainability of system designs and proposed system changes prior to the construction of physical prototypes. DEPTH contains a variety of components that collectively facilitate the design process and subsequent incorporation of this data into the Logistics Management Information (LMI) process, training support and electronic technical manuals.

Background - Virtual Human Modeling

A core element of DEPTH is a 3D virtual human model which simulates the motion of human maintainers and interacts with computer models of a system as shown in Figure 1.

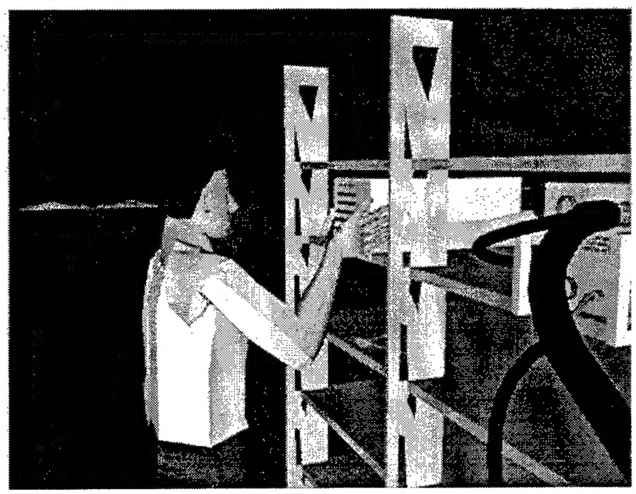


Figure 1: TransomJack™ interacting with a 3D CAD drawing

DEPTH uses the TransomJack™ Human Figure Model (HFM) developed by the University of Pennsylvania and commercially enhanced and supported by Transom Inc. (Ann Arbor, MI). Using DEPTH, the analyst can simulate maintenance procedures on a 3D Computer Aided Design (CAD) drawing to address maintainability design issues such as visibility, reach, accessibility and tool use.

The realistic modeling of humans is one of the largest challenges in computer graphics. It is far easier to model a room full of realistic objects than it is to create one realistic virtual human. Virtual humans have been

studied in computer graphics almost since the introduction of the medium. Computational models have evolved from wireframe stick figures, through simple polyhedral models, to curved surfaces, and even finite element models. Currently, 3D computer-generated characters are used in virtual reality systems, video games, movies, and television commercials. The applications of virtual human animation are limited only by our imagination. Although researchers have devoted significant efforts to representing the human body shape, the problem of realistic animation of the human body has not yet been satisfactorily solved.

Objective

Although in use by a variety of organizations, TransomJack has not been validated. The motion of the TransomJack HFM is based on a robotics formulation, which differs from actual human motion. If DEPTH is to provide reliable data about weapon system maintainability, the performance of the virtual human models must accurately reflect that of actual live maintainers. Inaccurate simulations can lead to erroneous design recommendations and potentially non-optimal designs.

The primary objective of this study is to increase confidence in DEPTH maintenance simulations through an iterative comparison of the performance of live humans and HFMs performing the same tasks. Closely related is the objective of providing feedback to the program developers in order to improve the accuracy and reliability of their product. A final objective is the development of a repeatable evaluation technique for DEPTH and other HFMs in general.

It is important to note that the intent of this initial study is not to *validate* that the model accurately emulates all maintenance tasks. The number of testable motions is enormous and it would take years to verify every one. This effort will provide the DEPTH developers with an indication of the degree of similarity between controlled human motion and HFMs, increasing our confidence that simulations are suitable for design evaluation. DEPTH developers will use this study to refine DEPTH's motion routines or TransomJack's robotics algorithms if large differences exist between virtual and live human motion. The data from this study may also be usable by other HFMs.

Motion Models and Motion Tracking

In DEPTH, TransomJack is driven by a set of Parallel Transition Networks (PaT Nets) called motion models which combine elementary movements into meaningful tasks. Motion models are a focus of this evaluation.

According to Vujosevic and Ianni (1996), the taxonomy of DEPTH's motion models are based on two approaches: (1) motion models follow "the Behavior Description Approach to task classification, where categories of tasks are formulated based upon observations and descriptions of tasks" and (2) motion models are "defined in a hierarchical fashion based upon behavioral processes, activities and specific behaviors."

TransomJack's inverse kinematic positioning utility may affect the performance of the motion models, thus affecting the outcome of this evaluation effort. The inverse kinematic "philosophy" assumes that the user is interested in spatial appearance, rather than joint angle positions (Badler et al., 1993). Thus, the transformation of spatial configuration into joint angles is computed using inverse kinematics which is an efficient computational method. When inverse kinematics are used in TransomJack to compute links with many degrees of freedom (such as the arm with wrist, elbow and shoulder), joint angles are not predictable, causing awkward elbow positions. The success of the DEPTH evaluation will depend upon the motion models' ability to overcome awkward body positions caused by TransomJack's inverse kinematics.

This study will compare HFM tasks with real human motions that are tracked using a motion tracking system called Flock of Birds (FOB) from Accession Technologies. Several pilot studies have been performed using FOB's data collection techniques, and several metal configurations were tested. It was found that metal interferes significantly with data collection. It was determined that data collection should ideally occur far from metal fixtures.

METHOD

Subjects

Twenty-four test participants will be recruited from an AL/HRGA subject pool. The subjects, ranging in age from 21 to 50, will take part in two data collection sessions: (1) anthropometric measurements and (2) motion measurements. To insure consistent motion data, all subjects must be right-handed or truly ambidextrous and able to lift thirty pounds over their head.

Materials

A variety of hardware pieces will be used in the evaluation process. A three panel peg board unit with non-metallic shelving units will be used to mock up each task as illustrated in Figure 2. The unit is six feet tall with ¼ inch peg holes. A 12" X 9" X 9" card board box with sand weights will be used during lifting, pulling, and pushing tasks. Two box handles are twelve inches apart and four inches from the base.

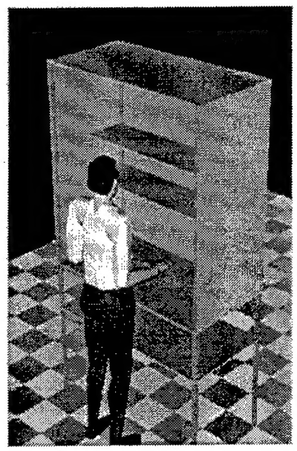


Figure 2: Simulated Workspace Mock-up in DEPTH

Data collection for the live mock-up tasks will be supported with the FOB and associated computer equipment. The FOB is a magnetically-based, six degree of freedom motion tracking system, determining both the position and orientation of the sensor. The sensors are strapped onto a human subject or inanimate object and transmit tracking information through receiver boxes to the host computer. For this study, the FOB has eight sensors with one sensor placed on the forehead, one on the right upper arm and one on the back of the right hand. Two FOB sensors will be placed on the objects of interest in the environment.. Refer to Table A-1 in the Appendix for a description of FOB sensor locations

The core element of the apparatus is a Silicon Graphics, Inc. (SGI) Onyx workstation. The Onyx, based on the Reality Engine 2™ graphics engine, is currently configured with two microprocessors, two raster managers, and 128MB of Random Access Memory (RAM). The Onyx hosts and runs the DEPTH software.

DEPTH will be used to generate HFMs, simulate the 3D workspaces, simulate the experimental tasks and collect motion data for the HFMs performing the experimental tasks. Qualitative comparisons of the motion data will also be done in DEPTH.

Procedure

The following test procedures represent the first attempt to evaluate DEPTH's motion models and to understand the process which may lead to future validation efforts.

Anthropometry

DEPTH uses a standard set of 19 body measurements (or anthropometric data) to automatically generate HFMs. Screen shots depicting the dimensions used to generate an HFM in DEPTH are shown in Figure 3.

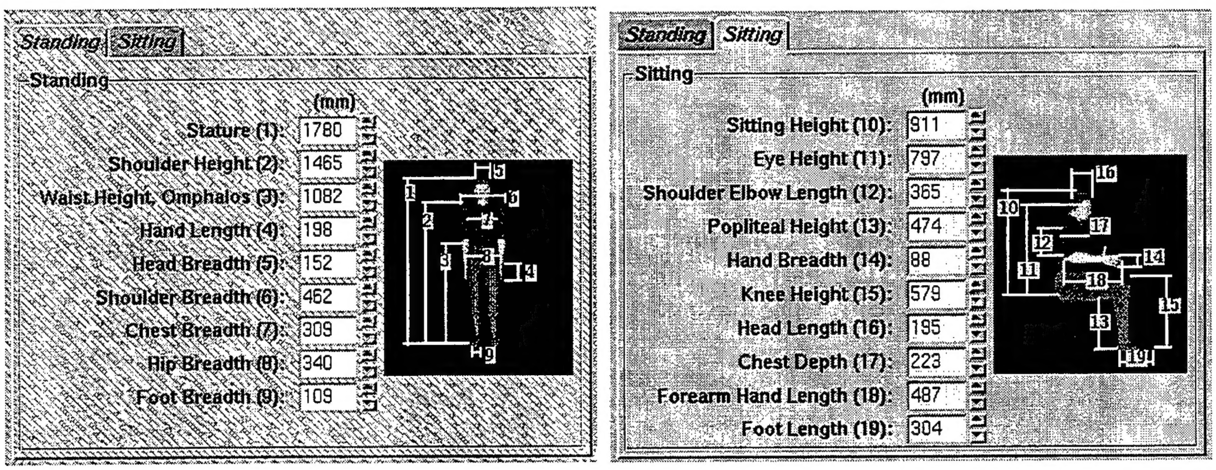


Figure 3: Input Screens for HFM Generation

This study will use the subject measurements from earlier research performed by Nemeth (1996). Nemeth collected body measurements from approximately 18 subjects and generated DEPTH virtual human models for each subject. Her study was used to determine if DEPTH can accurately generate HFMs. Refer to Nemeth (1996) for a complete description of the data collection process and the HFM generation method. If additional subjects are required, they will be measured using Nemeth's method.

Test Controls

Our primary interest is in insuring that elbow and hand positions are measured accurately. To accomplish this, we plan to control two sources of error, including metal and subject start and stop positions.

Collection of accurate position data by the FOB system is severely hindered by the presence of metal components in the experimental setting. The normal position error is approximately 0.35" and metal induces

random fluctuations. To combat this problem, metal in close proximity to the data collection site will be minimized. This "clean" distance is still being determined.

Another inherent source of error is poor dynamic control of subject movement. Since we are interested in elbow and hand positions, it is essential to control positions of other body parts. In general, this will be accomplished by controlling (1) foot position, (2) start and stop positions of hands, (3) table and shelf heights and (4) the type of tools used. These controls are described further for each task in the Appendix.

Tasks

We are evaluating two classes of tasks: simple tasks which incorporate one Motion Model and complex tasks which incorporate two or more Motion Models. The tasks represent common maintenance activities. The proposed tasks are listed in the Appendix.

Motion data will be collected for both the live human tasks and the HFM performing simulated tasks.

Human Motion Data Collection

The live human data will be collected through the FOB as points in space for the sensors located on the forehead, hands and elbows for each task. The Appendix provides, for each task, subject instructions, start/stop procedures, FOB sensor locations, statistical measures, and qualitative measures.

HFM Motion Data Collection

The mock-up workspace used for this study will be simulated in DEPTH along with each subjects representative HFM. Sites will be created on each HFM equivalent to the location of FOB sensors on each subject.

Simulations for each task will be developed in DEPTH. Task scenarios will be driven by motion models. Using the simulated mock-up workstation in DEPTH, each subject's HFM will be run for each task. The HFM data will be captured for each site as points in space in the DEPTH workspace, creating a profile of the elbow and hand motions as the HFM performs each task.

Data Analysis

The collected data will be analyzed both quantitatively and qualitatively for each task. The results of the analysis for each task will be summarized across body locations, joint positions, and/or angles. The resulting data will represent a cross-section of typical maintenance tasks and the associated accuracy of the HFM for each task.

Quantitative Motion Comparison

We are hypothesizing that DEPTH accurately simulates basic aircraft maintenance tasks. In particular, the points associated with the elbow, hands and head will be important as the arms and upper body are involved in most maintenance tasks and are a key determinant of reach and clearance. We believe that DEPTH's virtual human can reasonably mimic elbow, hand and head positions while performing similar tasks. Three pairs of statistical hypotheses are defined below:

Elbow Position

H_O: $\mu_{human} \neq \mu_{depth}$

H_1: $\mu_{human} = \mu_{depth}$

Hand Position

H_O: $\mu_{human} \neq \mu_{depth}$

H_1: $\mu_{human} = \mu_{depth}$

Head Position

H_O: $\mu_{human} \neq \mu_{depth}$

H_1: $\mu_{human} = \mu_{depth}$

All hypotheses involve a within-subjects design with a single independent variable, **Motion Type**, comparing the distance **(D)** between live human motion (Motion Type #1) and DEPTH virtual human motion (Motion Type #2). All hypotheses will be tested for each task, and each task will be repeated 5 times. Each task

will generate 6 data points (position data) representing different time-dependent phases (0%. 20%, 40%, 60%, 80% and 100%) of the tasks.

The null hypotheses, which will be tested for each task, specify that DEPTH figure positions will be different from actual human positions. Each null hypothesis will be tested ($p = .05$) for two possible outcomes:

(1) If the distance (**D**) between average human and depth figure positions, within-subjects per task, is not statistically equal to zero, then a null hypothesis can not be rejected. This means that average human and DEPTH figure positions are not equal.

(2) If the distance (**D**) between average human and depth figure positions, within-subjects per task, is statistically equal to zero, then a null hypothesis will be rejected. The alternative hypothesis states that average human and DEPTH figure positions are equal.

For each time phase (0%. 20%, 40%, 60%, 80% or 100%) per task, five 3D position coordinates will be collected for both the human and its corresponding DEPTH figure. Mean position coordinates will be calculated for the human and the DEPTH figure, and **D** will be computed between the mean coordinates. Distances will be compared using a $(D \times S)$ within-subjects design. The $(D \times S)$ computational formulas (Keppel, 1991) will be used to calculate the ***F*** statistic, which will be used to test the null hypothesis.

Since practice effects are a possibility, tasks will be counterbalanced. The tasks (See Appendix B where is B?) will be arranged in a Latin Square creating eight sequences. For a subject pool of 24, each sequence will be performed by three subjects. Post hoc analyses may include comparisons between male/female subjects and large/medium/small subjects. Right now, the subject pool is mostly male, and appropriate size classifications have not been defined based on available subjects. Other post hoc analyses may include various confidence intervals of HFM vs. human movement.

Qualitative Motion Comparison

In addition to the statistical analysis, the simulations will be subjectively compared with live motion. The HFM motion profile and stored data from the human subject will be placed side-by-side on a single display. An example of the motion profiles captured for several sites during a stand are depicted in Figure 4. This comparison

should allow us to identify obvious differences in the motion profile such as the position of major body parts (e.g. hands and elbows).

Figure 4: HFM Motion Profiles

This comparative process will help answer questions such as this: *Do DEPTH's motion models mimic the motions generated by a human subject?* For example, in turning a wrench do both the model and human hold their elbow up or tuck it in?

REFERENCES

Badler, N., Phillips, C., Webber, B. (1993). Simulating Humans. Oxford University Press, New York.

Boyle, E, Easterly, J., Ianni, J. (1990). Design Evaluation for Personnel, Training and Human Factors (DEPTH). Report No. AFHRL-TP-90-57. WPAFB, OH: Air Force Human Resources Laboratory.

Keppel, G.(1991). Design and Analysis: A Researcher's Handbook. Prentice Hall, Englewood Cliff, New Jersey.

Nemeth ,K. (1996). Problems Associated with Applying Anthropometric Methods for Ergonomic Design. Unpublished doctoral dissertation, Miami University, Oxford, OH.

Roebuck, J. A. (1993). Anthropometric Methods: Designing to Fit the Human Body. Human Factors and Ergonomics Society. Santa Monica, CA.

Vujosevic, R., and Ianni, J. (1996). Maintenance Motion Model Library in DEPTH. 1996 CALS Expo Proceedings.

ACRONYMS

AL/HRGA	Armstrong Laboratory, Logistics Research Division
CAD	Computer Aided Design
DEPTH	Design Evaluation for Personnel, Training, and Human Factors
FOB	Flock of Birds
HFM	Human Figure Model
LMI	Logistics Management Information
PaT Nets	Parallel Transition Networks
RAM	Random Access Memory
SGI	Silicon Graphics, Inc.

APPENDIX: MOTION DATA COLLECTION PROCEDURES

Table A-1: Flock of Bird Sensor Locations

	FOB Location
FOB Sensor 1	Backside of right hand, 4 cm from the wrist dorsal (Roebuck, 1993) along the long axis of the arm.
FOB Sensor 2	Backside of upper arm, 8 cm from the olecranon landmark (Roebuck, 1993).
FOB Sensor 3	Glabella landmark (Roebuck, 1993).

Table A-2: Grasp Wrench Task

Start Position	Subject is standing, looking straight ahead with hands and arms resting at side.
End Position	Wrench in right hand and right arm resting at side.
Instructions	Grab the wrench with the right hand and move the hand to its resting position at the side of the body.
Control Variables	Constant handle height, omphalion level, for all trials and subjects. Constant starting position (1" from table edge and hand length from subject) Constant starting orientation (perpendicular) of wrench for all trials and subjects. Constant starting position: feet are waist breadth apart. Constant position of left hand (side of body).
Statistical Measures	(1) Hand and (2) Elbow and (3) Head. (X, Y, Z) and (X deg, Y deg, Z deg) will be compared at 20% motion intervals. Six measures will be recorded: 0%, 20%, 40%, 60%, 80%, and 100%.
Qualitative/Subjective measures	Does the PaT Net model look similar to the FOB motion? Does the elbow, hand and Cervical motions generated by the PaT Net model exhibit controlled motion? Compare the PaT Net model motion to a 3-D FOB graphical volume.
PaT Net Model Comparison	Grasp (Vujosevic and Ianni, 1996)

Table A-3: Tightening Bolt Task

Start Position	Subject is standing, looking straight ahead with the wrench in right hand and the wrench attached to the bolt.
End Position	Subject is standing, looking straight ahead with the wrench in right hand and the wrench attached to the bolt.
Instructions	Tighten bolt with one ¼ turn.
Control Variables	Constant starting position of bolt (shoulder level) Constant starting orientation of wrench for all trials and subjects (90 degrees) Constant starting position, feet are waist breadth apart. Subject stands one hand length from bolt. Constant orientation (facing bolt) of subject for all trials. Constant position of left hand (side of body).
Statistical Measures	(1) Hand and (2) Elbow and (3) Head. (X, Y, Z) and (X deg, Y deg, Z deg) will be compared at 20% motion intervals. Six measures will be recorded: 0%, 20%, 40%, 60%, 80%, and 100%.
Qualitative/Subjective measures	Does the PaT Net model look similar to the FOB motion? Does the elbow, hand and Cervical motions generated by the PaT Net model exhibit controlled motion? Compare the PaT Net model motion to a 3-D FOB graphical volume.
PaT Net Model Comparison	Tighten fastener with tool (Vujosevic and Ianni, 1996)

Table A-4: Loosen Bolt Task

Start Position	Subject is standing, looking straight ahead with the wrench in right hand and the wrench attached to the bolt.
End Position	Subject is standing, looking straight ahead with the wrench in right hand and the wrench attached to the bolt.
Instructions	Loosen bolt with one ¼ turn.
Control Variables	Constant starting position of bolt (shoulder level) Constant starting orientation of wrench for all trials and subjects (180 degrees) Constant starting position, feet are waist breadth apart. Subject stands one hand length from bolt. Constant orientation (facing bolt) of subject for all trials. Constant position of left hand (side of body).
Statistical Measures	(1) Hand and (2) Elbow and (3) Head. (X, Y, Z) and (X deg, Y deg, Z deg) will be compared at 20% motion intervals. Six measures will be recorded: 0%, 20%, 40%, 60%, 80%, and 100%.
Qualitative/Subjective measures	Does the PaT Net model look similar to the FOB motion? Does the elbow, hand and Cervical motions generated by the PaT Net model exhibit controlled motion? Compare the PaT Net model motion to a 3-D FOB graphical volume.
PaT Net Model Comparison	Loosen fastener with tool (Vujosevic and Ianni, 1996)

Table A-5: Pull Box Task

Start Position	Subject is standing, looking straight ahead with hands and arms resting at side. The box will be positioned on a table in front of the subject.
End Position	The box will be on a table with right hand holding the box handle.
Instructions	(1) Reach for the box and grab the handle with right hand. (2) Pull the box towards the far edge of the table; retract right arm to move box away.
Weight conditions	(1) Empty box (2) Empty box plus 5% of body weight (3) Empty box plus 10% of body weight
Control Variables	Constant handle height, omphalion level, for all trials and subjects. Constant starting position of box, Forearm-Hand Length from subject to box handle. Constant stopping position of box, Hand Length from subject to box handle. Constant orientation of box for all trials and subjects (box handle facing subject). Constant starting position, feet are waist breadth apart. Constant orientation (facing table) of subject for all trials. Constant position of left hand (non-movement of left hand, side of body).
Statistical Measures	(1) Hand and (2) Elbow and (3) Head. (X, Y, Z) and (X deg, Y deg, Z deg) will be compared at 20% motion intervals. Six measures will be recorded: 0%, 20%, 40%, 60%, 80%, and 100%.
Qualitative/Subjective measures	Does the PaT Net model look similar to the FOB motion? Does the elbow, hand and Cervical motions generated by the PaT Net model exhibit controlled motion? Compare the PaT Net model motion to a 3-D FOB graphical volume.
PaT Net Model Comparison	Grasp or Hold (Vujosevic and Ianni, 1996) Pull (Vujosevic and Ianni, 1996)

Table A-6: Lift Box Task

Start Position	Subject is standing, looking straight ahead with hands and arms resting at side. The box will be positioned on a table in front of the subject.
End Position	Subject is standing and holding the box on the shelf.
Instructions	(1) Reach for the box; place right hand on the right side of the box and place left hand on the left side of the box. (2) Pull arms upward to move object up; lift box to shelf.
Weight conditions	(1) Empty box (2) Empty box plus 5% of body weight (3) Empty box plus 10% of body weight
Control Variables	Constant starting position of box handles (omphalion level) Constant starting orientation of box for all trials and subjects (box handles on side of box relative to subject). Constant starting position of box, Hand Length from subject to box handle. Constant stopping position of box, Forearm-Hand Length from subject to box handle. Constant starting position, feet are waist breadth apart Constant orientation (facing table/shelf) of subject for all trials. Constant handle height at the end to the lift (shoulder level) Control box upward movement (a larger, second shelf will be placed 9" above the lower shelf). Use guidelines to mark stop positions on the shelf.
Statistical Measures	(1) Hand and (2) Elbow and (3) Head. (X, Y, Z) and (X deg, Y deg, Z deg) will be compared at 20% motion intervals. Six measures will be recorded: 0%, 20%, 40%, 60%, 80%, and 100%.
Qualitative/Subjective measures	Does the PaT Net model look similar to the FOB motion? Does the elbow, hand and Cervical motions generated by the PaT Net model exhibit controlled motion? Compare the PaT Net model motion to a 3-D FOB graphical volume.
PaT Net Model Comparison	Grasp or Hold (Vujosevic and Ianni, 1996) Lift (Vujosevic and Ianni, 1996)

Table A-7: Push Box Task

Start Position	Subject is standing, looking straight ahead with hands and arms resting at side.
End Position	The box will be on a table with right hand holding the box handle.
Instructions	(1) Reach for the box and grab the handle with right hand. (2) Push the box towards the far edge of the table; extend right arm to move box away.
Weight conditions	(1) Empty box (2) Empty box plus 5% of body weight (3) Empty box plus 10% of body weight
Control Variables	Constant handle height, omphalion level, for all trials and subjects. Constant stopping position of box, Forearm-Hand Length from subject to box handle. Constant starting position of box, Hand Length from subject to box handle. Constant orientation of box for all trials and subjects (box handle facing subject). Constant starting position, feet are waist breadth apart Constant orientation (facing table) of subject for all trials. Constant position of left hand (non-movement of left hand, side of body).
Statistical Measures	(1) Hand and (2) Elbow and (3) Head. (X, Y, Z) and (X deg, Y deg, Z deg) will be compared at 20% motion intervals. Six measures will be recorded: 0%, 20%, 40%, 60%, 80%, and 100%.
Qualitative/Subjective measures	Does the PaT Net model look similar to the FOB motion? Does the elbow, hand and Cervical motions generated by the PaT Net model exhibit controlled motion? Compare the PaT Net model motion to a 3-D FOB graphical volume.
PaT Net Model Comparison	Grasp or Hold (Vujosevic and Ianni, 1996) Push (Vujosevic and Ianni, 1996)

Table A-8: F-16 Advance Central Interface Unit (ACIU) Removal

Start Position	Subject is standing, looking straight ahead with hands and arms resting at side.
End Position	The ACIU will be placed on the floor in front of the subject.
Mock-up setting	A simulated ACIU box, with a two inch handle, will be positioned on a shelf at stature height. The handle will face the subject.
Instructions	With the right hand, reach for the ACIU box. Grasp the handle. Pull the box towards the edge while placing the left hand under the ACIU. Place the ACIU on the ground in front of feet.
Weight condition	Empty box plus 10% of body weight
Control Variables	Constant shelf height (stature level) for all trials and subjects. Constant starting position and orientation of ACIU box for all trials and subjects. Constant starting position and orientation of subject for all trials, Subject will face the handle at a 45 degree angle with the right foot furthest from the handle. The left foot will be one Hand Length away from shelving unit. The feet will be waist breadth apart.
Statistical Measures	(1) Hand and (2) Elbow and (3) Head. (X, Y, Z) and (X deg, Y deg, Z deg) will be compared at 20% motion intervals. Six measures will be recorded: 0%, 20%, 40%, 60%, 80%, and 100%.
Qualitative/Subjective measures	Does the PaT Net model look similar to the FOB motion? Does the elbow, hand and Cervical motions generated by the PaT Net model exhibit controlled motion? Compare the PaT Net model motion to a 3-D FOB graphical volume.
PaT Net Model Comparison	Grasp (Vujosevic and Ianni, 1996) Pull with right hand (Vujosevic and Ianni, 1996) Hold with left hand